ABSTRACT: The tentative and revisionary character of scientific knowledge is believed to play a central role in nature of science (NOS) studies by teachers, researchers, and curriculum developers. However, some educational researchers and scholars have recently expressed serious concerns about the view of tentativeness and change espoused in the science education literature claiming that it is simplistic, one-dimensional, inconsistent, irresponsibly vague, and self-contradictory. Despite these concerns, there are few detailed examples of how these types of problems manifest themselves in the science education literature and the difficulties they might pose for learners and other researchers. Accordingly, this article isolates and critically examines a single foundational proposition about the tentativeness of science made by leading NOS researchers. It is demonstrated that this generalization has some important inconsistencies and limitations that are problematic at the philosophical and instructional level. Throughout the article, it is argued that a logico-linguistic analysis of epistemic propositions made by researchers is desirable in NOS studies and that seemingly benign propositions can give rise to different viable, yet diametrically opposed, interpretive frameworks.

FRENCH ABSTRACT:

In a paper presented at the 2001 international meeting of the Association for the Education of Teachers in Science (AETS), Abd-El-Khalick, Lederman, Bell, and Schwartz discuss issues related to the development and refinement of the View of the Nature of Science Questionnaire (VNOS) – an instrument aimed at validly and meaningfully assessing learners’ conceptions of the nature of science. This AETS conference paper was later published in the Journal of Research in Science Teaching (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), and the VNOS is now a frequently used instrument by science education researchers.

In the process of justifying the VNOS and providing contextualizing text for this instrument, Lederman, et al. (2002) make three very important points that relate to the nature of science (NOS). First, they clearly point out that there is an important difference between the nature of science such as epistemological issues, values, and assumptions and the processes of science such as observing, hypothesizing, and experimenting – and that the two are often conflated. Second, they effectively argue that the tentative and revisionary character of science plays a central role in nature of science studies. Third, they argue that there is a general consensus among science educators, philosophers, historians, and sociologists of science related to key nature of science concepts. Each of these three points is
reasonable and well substantiated in the current science education literature and go unchallenged here.

What is challenged, however, is the logic and praxis of the authors’ contention that, “similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (Lederman, et al., 2002, p. 499). In a prior publication that reviews attempts at improving science teachers’ conception of the nature of science, Abd-El-Khalick & Lederman (2000) express a similar thought and viewpoint that “a review of the research literature on NOS needs to be undertaken and ‘read’ from the standpoint that, much like scientific knowledge, conceptions of NOS are necessarily tentative and historical” (p. 668).

What the authors mean to convey by these statements, it would seem and appear, is the view that conceptions of the nature of science have shifted over time, mirroring shifts in the philosophy, history, and sociology of science (e.g., the “Pre-Kuhn” versus the “Post-Kuhn” Era), and that these shifts have had an impact on how the science education community has defined the nature of science over the past century.

On the surface, it is hard to find fault with the idea that conceptions of the nature of science are tentative and dynamic. However, when analyzed in a systematic manner, there are key and highly significant problems or at least important limitations with the view that “similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (Lederman, et al., 2002, p. 499). More specifically, the problem lies with stating that the larger more global epistemic conception and framework of the nature of science is tentative and then applying this generalization to each of the tenets of the nature of science without important qualifications and exceptions (such as addressing the different degrees and meanings of tentativeness as they relate to each tenet). These (sub-level) tenets, principles or concepts that define and exemplify the nature of science presently are outlined by Lederman, et al. (2002) and are reinforced in the National Science Education Standards (National Research Council – NRC, 1996) and the science education literature in general. These tenets include but are not limited to the following five claims:

1. Science is empirical;
2. Science is a human enterprise;
3. Science involves creativity and human imagination;
4. Scientific knowledge is subjective and theory laden;
5. Scientific knowledge is stable yet tentative.

It should be mentioned that each of these five tenets are largely consistent with and define the Post-Kuhn Era and view of the nature of science, and that science educators have identified the tentative nature of science as the central tenet over the past decade (see Perla, 2006).

The contention that our general conception of the nature of science is itself tentative is inconsistent and fraught with difficulties when applied to the five tenets above, and especially when applied to the tentativeness of scientific knowledge (tenet #5), and requires some clarification and discussion. This article demonstrates how the view that
our conception of the nature of science is tentative and is (a) problematic and opens the door to some strange philosophical and instructional implications and (b) suggests a confusion between individual nature of science tenets and the more comprehensive and general nature of science framework that subsumes these tenets. Moreover, part of the importance of this particular assertion by Lederman, et al. (2002) is that it is a meta-epistemological assertion, or an assertion that attempts to subsume and organize individual epistemic claims, such as the five tenets above. This fact alone makes this assertion worthy of intense scrutiny in order to gauge its limitations, validity, and generalizability.

What follows is a brief critical analysis of Lederman, et al.’s (2002) contention that “similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (p. 499) and an exploration into the logical and instructional consequences and implications of this statement. Some may argue that the point of this article is trivial and “hair-splitting” over terminology, and that it throws the baby out with the bath water, or that the gist of this statement is easily discernable without diving into a logico-linguistic analysis. However, it should be stressed that (a) the human language is extremely vague, subtle, imprecise, often amorphous, and packed with hidden meaning – especially epistemic terms and concepts (Thagard & Beam, 2004); (b) the science education literature has clearly demonstrated that students (K-16) have difficulty understanding epistemic and nature of science-related terms and concepts such as proof (Lederman & O'Malley, 1990) and tentativeness (Johnson & Southerland, 2001); and (c) teaching nature of science in the K-12 setting and beyond is an extremely difficult endeavor (Olson & Clough, 2003). Because nature of science concepts are fundamentally epistemic concepts (Lederman, 1992), they are and should be subject to the linguistic-semantic (propositional) scrutiny that defines the field of epistemology and its attempt to clarify the meanings of words and sentences in the analytic tradition and spirit of Russell and Wittgenstein. In fact, the method of analysis used in this article is in many ways an attempt to apply Wittgenstein’s (1922/2003, 1963) view of philosophy – as an elucidatory versus descriptive practice that aims at the logical clarification of thought and language – to the science education literature and specifically nature of science studies and propositions. Indeed, this article focuses more on the context of justification than the context of discovery (see Reichenbach, 1938), as the former context (in its pure form) has never really taken hold in educational research and analyses, particularly in the “post-Kuhn” and postmodern era.

Moreover, the issue of conceptual clarity and logical coherence addressed in this article through the analysis of a single (and to some degree contradictory) statement about tentativeness may be no more different from the types of questions, thoughts, and confusions of students that may or may not become explicit and discussed by the student or teacher in the classroom. Inaccurate, incomplete, trivial, and illogical interpretations of tentativeness in science – on the teacher or student’s part – is surely subversive to the goal of scientific literacy and
a deeper appreciation of the scientific enterprise. As Johnston and Southerland (2001) argue in their study of the multiple meanings of tentative science among college learners, “students’ use of a specific meaning of ‘tentative’ is dependent upon their underlying epistemological standards for science” (p. 1), and that “an apparently slight misinterpretation of science’s tentativeness on the part of a student may be indicative of a more fundamental misunderstanding regarding science as a way of knowing” [italics added] (p.1).

Slight misinterpretations of science’s tentativeness are bad enough instructionally, but are only exacerbated when we consider that the foundational proposition of nature of science studies – that science is stable yet tentative – is flawed logically. Douglas Allchin (2004) is one of a handful of people to recognize this problem when he states “the phrase ‘science is tentative but durable’ is irresponsibly vague, if not self-contradictory. Science educators therefore need to adopt a more textured notion of the nature of science” (p. 943). Philosophers of science have long worried about the use of careless language and thinking when discussing change in science, as evidenced by Laudan’s (1984) view that “in trying to characterize the mechanism of theory change, we [philosophers of science] have tended to lapse into sloppy language for describing change” (p. 68).

When dealing with the philosophical and epistemic ideas and concepts that define contemporary nature of science studies (which are admittedly complex), care must be taken in how these ideas and concepts are stated and framed – especially in instructional contexts. As Wittgenstein reminds us, “philosophical problems arise when language goes on holiday” (as cited in Thagard & Beam, 2004, p. 512). It is reasonable to rephrase Wittgenstein’s simile in an educational context and assert that “instructional problems arise when language goes on holiday.”

However, recognizing linguistic and conceptual inconsistencies, problems, or anomalies also provides opportunities for further elaboration and precision of understanding and meaning, which is the intent of this article. At a bare minimum, the proposition under examination here by Lederman, et al. (2002) provides the intellectual fodder to demonstrate how formal logic can be applied to important assertions relative to nature of science (and other areas) to determine their validity and soundness or lack thereof.

Accordingly, the following two sections establish the idea that nature of science studies and instruction are fundamentally epistemic endeavors and that a central (epistemic) feature of scientific knowledge is the concept of tentativeness. Having established these two points, the article introduces a simplified nature of science framework (see Figure 1) that is subsequently used to clarify problems with the view that “similar to scientific knowledge, conceptions of NOS are tentative and dynamic” (Lederman, et al., 2002, p. 499). The article concludes with a discussion and recap of the key points developed in this article and implications for future research in the area of nature of science instruction and science education.
Nature of Science Instruction as an Epistemic Endeavor

Although no standard definition of the nature of science exists, the educational literature generally associates this concept with the epistemology of science, or the values and assumptions inherent in the development of scientific knowledge (Lederman, 1992). Specifically, this epistemological view among science educators emphasizes the idea that scientific knowledge is stable yet tentative, empirically based, inferential, subjective, theory-laden, and influenced by the social and cultural milieu (American Association for the Advancement of Science, 1993; National Research Council, 1996). Many of these epistemic features of the nature of science identified by educators have been substantiated by professional philosophers of science (Eflin, Glennan, & Reisch, 1999) and empirically validated by a wide range of nature of science experts (Osborne, Collins, Ratcliffe, Millar & Duschl, 2003).

Broadly defined, epistemology is the study of the nature of knowledge. Psychologists have traditionally viewed epistemology as a more descriptive endeavor – that is, understanding how people do think and reason – whereas philosophers of science view epistemology as a prescriptive endeavor – that is, understanding how people should think and reason (Thagard, 1988). Whether you tend more toward the descriptive or prescriptive model, epistemology is a quest to understand the nature of knowledge and the process of meaning-making by addressing fundamental problems. If the nature of science is an epistemic endeavor, then we need to understand what epistemology is and the types of problems it addresses. Bertrand Russell described the aim of epistemology well when he stated that the fundamental problem of epistemology is to understand “the relation subsisting between thoughts, words, or sentences, and that which they refer to or mean” (cited in Wittgenstein, 1922/2003, pp. xvii-xviii). If the nature of science content is epistemic content, there is no getting around the need to critically analyze the words and sentences we use in nature of science studies and research if we are to develop a more accurate, meaningful, and contextualized view of the nature of science and to reduce the likelihood of confusion among students. On this point, there is a good bit of concordance between analytic philosophy, epistemology, and education – the goal to establish clear and logical connections between what we say and what we mean and hope to convey and teach – connections that represent the foundation of Dewey’s (1910/1991) educational philosophy and much of modern learning theory and cognition (Ashcraft, 2002).

Scientific Knowledge is Tentative

As stated above, the tentative and revisionary character of scientific knowledge is believed to play a central role in nature of science studies by teachers, researchers, and curriculum developers. As Lederman and O’Malley (1990) point out, much of the research regarding the nature of science in an instructional context has been based on the belief that
“tentativeness is the primary attribute of scientific knowledge” (p. 225). Indeed, for the past six decades instruments designed to gauge student understanding of the nature of science have to some degree and at varying levels of sophistication involved measures of tentativeness and change (Lederman, et al., 2002; Aikenhead, 1987; Lederman & O’Malley, 1990; Ruba & Anderson, 1978; Vitroge, 1967; Wilson, 1954). This priority, focused on the tentative, dynamic, and changing nature of scientific knowledge, has developed gradually over the past 50 years following developments in the history and philosophy of science and cognitive psychology and has played an increasingly important role in science education (Duschl, 1994). Indeed, it is now somewhat of a tautology to state that scientific knowledge is stable yet tentative (whatever this may actually mean). But having established the idea that scientific knowledge is tentative and dynamic does not mean that all or most scientific knowledge is tentative at the .5 (as opposed to the .0005) level of correctness with a 50% chance of being (significantly) revised (relative to core as opposed to auxiliary theoretical principles or facts), and this same tautological claim is not the same as having established the idea that our conceptions of nature of science are tentative (or even close to establishing such a claim) – even though such a claim is an intuitively appealing idea that may be true to some degree and with important qualifications as discussed in the next two sections of this article. Making overly simplistic sweeping claims and then sweeping claims from those claims most often sweeps meaningfulness, clarity, preciseness, and highly accurate assertions and claims out the door, and it is for these very reasons that we must be very cautious about sweeping claims and examine and analyze them closely in detail for both misrepresentations and problems. The following two sections provide this type of rigorous analysis relative to the proposition under examination here that our general conception of nature of science is tentative.

**Simplified Nature of Science Framework**

Before addressing the logical concerns and problems relative to the view that our general conception of the nature of science is tentative, a simplified framework for specific nature of science tenets as outlined by Lederman, et al. (2002) is provided in the concept map in Figure 1 with some modifications. The general conception of nature of science is identified by a node (bubble) labeled with a capital letter A and is assumed to be tentative, while the subordinate node (Epistemology of Science) is labeled with a capital letter B. Off the B node are five of the tenets of nature of science identified by Lederman and colleagues that are numbered 1-5, respectively. It should be pointed out that the epistemology of science node (node B) and the five associated nature of science tenets in Figure 1 are derived largely from the historical and philosophical study of science and are agreed upon most science education researchers. Directly beneath nodes 1-5 are three alternate node sets (1a-5a, 1b-5b and 1c-5c) that are replacement nodes for nodes 1-5 used to demonstrate different (logically possible) interpretations of
each of the five nature of science tenets as well as different reasoning paths in the concept map. Each of the bubbles in the alternate node sets in Figure 1 includes an adverb (i.e., extremely, somewhat, and not) that roughly qualifies the (ordinal) degree or level to which an individual understands and believes the tenet to be present in science at some point in time.

Precisely defining, exploring, mapping, and validating these qualified nature of science tenets or scale – either from a historical or contemporary perspective – goes beyond the scope of this article, but is a logical next step of this research. The adverbs are used here only to establish a differentiated conceptual framework and scale to develop the formal arguments that follow. In fact, one of the main assumptions required for the arguments that follow is that the presence of individual nature of science tenets can be differentiated by degree along an ordinal scale.
As discussed next, all node sets in Figure 1 represent logically possible interpretations of science under the assumption that our general conception of nature of science is tentative. The concept map in Figure 1 allows one to follow the chains of reason and logical arguments introduced in the next section of the article. The concept map also simulates the many different viable, and in some cases diametrically opposed, interpretive frameworks and schemas that can arise from the epistemic proposition under examination here. Based on results from the empirical literature in science education and cognitive psychology over the past three decades, it is reasonable to assume that a student, teacher or researcher’s preference for a particular node set (or any combination of nodes) is associated with their own epistemological standards, as well as their underlying epistemological standards for science (see Perla, 2006).

**Logical Problems with a Tentative Conception of the Nature of Science**

Assuming our general conception of the nature of science is tentative (bubble A in Figure 1) it is difficult to conceptualize and understand some of the possible effects of this tentativeness on the subordinate tenets of the nature of science (bubbles 1-5 in Figure 1) without some clarification. For example, let us examine tenet #1 (science is empirical) and tenet #2 (science is a human endeavor) in Figure 1 knowing the same points could be made for tenets #3-5. Assuming the general conception of the nature of science is tentative (node A), does not exclude the possibility that science is *extremely* empirical (path A-B-1a in Figure 1) or *somewhat* empirical (path A-B-1b), or that it is *extremely* a human enterprise (path A-B-2a) or *somewhat* of a human enterprise (path A-B-2b). Certainly none of these propositions or paths in the concept map, although vague, is extraordinary, counter-intuitive, or difficult to accept. However, assuming the general conception of the nature of science as tentative, does not exclude the possibility that science is *not* empirical (path A-B-1c) or that it is *not* a human enterprise (path A-B-2c). These latter two consequences are possible logically (even though they might strongly jolt our conceptions and schemas) because once we accept the possibility that our general conception of the nature of science is tentative (node A), then all subordinate tenets that constitute this general conception are subject to change also; if the subordinate tenets (by inheritance) are subject to change with no reference to the degree or limit to that change, then we cannot rule out the possibility that the tenets themselves can be rejected (i.e., complete change; nodes 1c-5c). In fact, explicitly pointing out that conceptions of the nature of science are tentative, as Lederman and colleagues (2002) do, is in many ways an invitation to explore the implications of the statement (or else why point it out or make the claim).

Surely, most science education researchers who accept the proposition that our general conception of the nature of science is tentative appreciate the idea that although science is empirical and a human enterprise, the issues surrounding the empirical and human
nature of science are subject to some degree of change and reformulation and not complete rejection. But this more nuanced and formalized view is a view that might only be inferred by someone with extensive knowledge and experience with nature of science studies, and possibly not students and perhaps not many science educators who read science education journals and papers – many of whom may take these assertions and their logical consequences too literally or not literally enough, as the case may be. Nevertheless, it is still a logical possibility and consequence that under the assumption that our general conception of the nature of science is tentative, that science is not empirical, nor a human enterprise. To a sophisticated reader, the ambiguity and possible contradiction in these examples is perhaps tolerable conceptually or ignored, but one would have to ask why these problems exist and have the question well answered to accept or tolerate this level of contradiction. However, to a non-sophisticated reader or student these types of contradictions may be utterly confusing and highly problematic – even if they are never explicitly stated or (partially) represented by the student.

To make matters more confusing, the central tenet of nature of science studies (the idea that scientific knowledge is stable yet tentative) becomes extremely convoluted under the assumption that our general conception of the nature of science is also tentative. What exactly does it mean to say or imply that scientific knowledge is extremely tentative (path A-B-3a) or somewhat tentative (path A-B-3b)? As mentioned earlier, different degrees, types, and meanings of tentativeness and change are identified by philosophers of science, science educators, and students, yet a more textured view of change does not appear to be an instructional priority despite the centrality of the tentativeness concept in nature of science studies (Allchin, 2004). Further, if we presently describe our conceptions of the nature of science as tentative without qualification, then we are essentially saying that the tentativeness of scientific knowledge is tentative, which does not exclude the possibility that scientific knowledge is certain insofar as certainty is the contraposition of tentativeness (a strange, but logically possible consequence in this example as demonstrated in path A-B-3c). This latter position is certainly not a tenable conclusion today as there is almost universal agreement that scientific knowledge is tentative – and tentative on many different levels; indeed, if the history of science has demonstrated anything, it has certainly demonstrated that scientific knowledge is subject to varying degrees and kinds of change.

But there is a difference between saying that scientific knowledge is tentative and that our conception of the nature of science is tentative. As mentioned above and shown in Figure 1, the idea that scientific knowledge is tentative is but one of many possible aspects (or tenets) that constitute our general conception of the nature of science, which is a larger (meta) epistemological system and network of ideas. So when Lederman, et al. (2002) – or anyone – state that “similar to scientific knowledge, our conceptions of the nature of science are also tentative,” they clearly recognize a distinction between scientific knowledge and the
more comprehensive and general nature of science framework. But by making this assertion, they confuse scientific knowledge with the general conception of the nature of science and are committed (by definition) to the possibility (however small it may be) that scientific knowledge is not tentative (nor human, empirical, theory laden, or creative). The logical problem and inconsistency here is that science is largely defined as claims, assertions, views, and theories that are falsifiable (Popper, 1969) and subject to continuous modifications, alterations, refinements, and rejections (Losee, 2004; Suppe, 1974). Scientific knowledge, therefore, is **without question** and **by definition** tentative, albeit to different degrees.

In other words, the tentativeness of science (from an **individual NOS tenet perspective**) is not and cannot be tentative (from a **comprehensive and general NOS perspective**) without important qualifications and the limits. To argue otherwise, is to argue that our general conceptions of the nature of science (whatever they may be at any point in time) have little to no bearing on or relation to the subordinate propositions and tenets that define these conceptions at the operational and instructional levels (i.e., a problem of praxis). To conclude that similar to scientific knowledge our conceptions of the nature of science are tentative and dynamic based on transitions in historical, sociological, or philosophical thinking without taking into account the subordinate propositions that define these general views is highly problematic because it creates a disconnect between the general conception of the nature of science and its specific and defining tenets.

The argument outlined in this section thus far suggests that our general conception of the nature of science may not be tentative at all at one level and is tentative at other levels only with important qualifications and a more differentiated view of tentativeness. The general argument developed here against the view that our general conception of the nature of science is tentative can be framed in the formal language of philosophy, specifically the form of argument known as **modus tollens** (see below). In fact, each of the five nature of science tenets in Figure 1 can be framed using the **modus tollens** form to demonstrate the limitations and difficulties with the proposition that our general conception of nature of science is tentative. For the sake of brevity, we introduce, develop, and discuss only one of the nature of science tenets in **modus tollens** form, specifically tenet #3 in Figure 1 that addresses the tentativeness of scientific knowledge, which is believed to be the central and key nature of science tenet presently by science education researchers.

We begin with the **modus tollens** form, which includes the following two premises and conclusion:

Premise (1): If P then Q
Premise (2): Not-Q

Conclusion: Not-P
This general (logical) argument form and its associated propositions is described as *a priori* (since the truth or falsity of this argument can be determined by pure reason prior to any observation), and *analytic* (since only the meaning of the words and not any factual content needs to be considered to determine the truth of the claim). For example, the proposition “All tall men are tall” is an analytic proposition because its truth is based only on the meaning and use of the word tall; no observations are needed to determine that this proposition is true.

Next, we populate and instantiate the standard *modus tollens* form with the specific content and propositions discussed earlier in this article as outlined in Figure 1. Accordingly, the “If P” region of premise (1) is populated with Lederman, et al.’s (2002) assertion in premise form: “If our general conception of NOS is tentative,” while the “then Q” region of premise (1) becomes one of the consequences of this assertion established in this article and in Figure 1: “Then scientific knowledge may be absolute.” Following the *modus tollens* form, premise (2) becomes the much agreed upon (although vague and undifferentiated) statement: “Scientific knowledge is not absolute.” The conclusion that logically follows premise (1) and premise (2) is: “Our general conception of NOS cannot be tentative.”

This instantiation and population of the *modus tollens* form comes together to create a formal argument. Since it is customary in the field of logic to name arguments, we refer to this argument as the **Tentative Argument** and it is introduced below:

1. If our general conception of NOS is tentative, then scientific knowledge may be absolute;
2. Scientific knowledge is not absolute;
3. Our general conception of NOS cannot be tentative.

In terms of the above argument, this article established premise (1) as being true, while premise (2) is already widely accepted as being true. The Tentative Argument is a (deductively) valid argument because the premises logically imply or entail the conclusion. Because the premises are true and the argument valid, the Tentative Argument is sound. Generally speaking, sound arguments are the highest standard of argument in philosophy and formal logic because they are both logically valid and true (Curd, 1992).

What the Tentative Argument demonstrates is the central feature and aim of formal logical analysis – the study of the form, relation, and implication of propositions. In accord with this view of formal logic and analysis, Kemeny (1959) states:

Thus we can sum up by saying that Logic considers the form of propositions. It starts out by considering statements. It studies the meanings of the words occurring and the rules of syntax according to which words are compounded. Finally it arrives at the abstract form of the proposition expressed by the statement. What Logic wants to know is whether a proposition of this form is necessarily true – or necessarily false. (p. 20)

Using the framework described by Kemeny, and the *modus tollens* form above, we conclude that the proposition that “similar to scientific
knowledge, conceptions of NOS are tentative and dynamic” is false at the formal level of analysis and requires reformulation.

What may not be obvious, yet is critically important, in the above example and transformation is that we used the very generic and logically structured *modus tollens* template that relies on *a priori* and *analytic* propositions to develop a specific argument (the Tentative Argument) that involves less rigorous, factual, and observational propositions (which are know as *synthetic* propositions). Because synthetic propositions require some observation, they are necessarily *a posteriori*. Indeed, premise (2) of the Tentative Argument is based on much factual observation and prior analysis that has convincingly demonstrated that scientific knowledge is not absolute. So the transition from the general *modus tollens* template to the Tentative Argument involves a fundamental transformation of the types of propositions used. Thus, the more formal and rigorous *modus tollens* template and form provided the logical structure and framework from which to develop the Tentative Argument and to clearly and succinctly examine some of the logical implications, inconsistencies, and limitations of the view that our general conceptions of nature of science are tentative – problems and insights that might have otherwise gone unnoticed.

And herein lies whatever value might be gleaned from a rigorous and formal (mathematical) analysis of propositions: the uncovering of new facts and limits that can be addressed and possibly expand our knowledge and the quality of our thinking. As Kemeny (1959) points out in his classic discussion of the role and virtue of mathematics, logic, and propositional analysis: “sometimes things follow from the meaning of words that are so far from obvious that it takes a good mathematician [or logician] several weeks or even years of painstaking labor to prove them” (p. 22). Kemeny goes on to note that “while in a sense mathematics [and logic] bring us nothing new, since it does no more than analyze the meanings of words, it brings us facts that are new to us, facts we did not realize we possessed” (p. 22).

However, it should be pointed out that using an analytic/a priori form of analysis, although a highly useful and structured propositional template and starting point, to analyze synthetic claims does create some problems (as all transformations do), because there are different criteria for determining the validity of analytic and synthetic propositions. This concern and issue is addressed effectively by Ayer (1952) in the following passage:

In saying that we propose to show “how propositions are validated,” we do not of course mean to suggest that all propositions are validated in the same way. On the contrary we lay stress on the fact that the criterion by which we determine the validity of an *a priori* or analytic proposition is not sufficient to determine the validity of an empirical or synthetic proposition. For it is characteristic of empirical propositions that their validity is not purely formal. To say that a geometrical proposition, or a system of geometrical propositions, is false is to say that it is self-contradictory. But an empirical proposition, or a system of empirical propositions, may be
free from contradiction, and still be false. It is said to be false, not because it is formally defective, but because it fails to satisfy some material criterion. And it is our business to discover what the criterion is. (p. 90)

As Ayer clearly points out above, it is important to recognize and conceptualize the differences in the criteria we use to assess and formally validate analytic and synthetic propositions. The Tentative Argument clearly involves factual (synthetic) propositions (i.e., the observations and related statements that scientific knowledge is not absolute but tentative), the validity of which cannot be purely derived from formal analysis (at least not entirely). However, the Tentative Argument also addresses and brings to light an important self-contradiction relative to the general conception of the nature of science and its defining tenets, and formal analysis is well suited to frame and isolate such contradictions, as this article demonstrates. Understanding exactly what happens to synthetic propositions when placed in an analytic model is still an unresolved issue in philosophy (and may always be such), but suffice to say there is a place for formal analysis in identifying and representing problematic, inconsistent, and self-contradictory propositions in nature of science research and educational research in general.

The critical linguistic model and approach used in this article is not presently a common form of analysis in science education research. The main thesis of this article suggests that formal propositional analysis may serve an important function as a tool to analyze research in science education, and it is most certainly a method that compliments nature of science studies (with its focus on epistemology and philosophy) and science education (with its focus on critical thinking and scientific literacy). The formal method used here (which is extremely critical, formal, and focused) contrasts the method used by Lederman, et al. relative to the proposition under examination here (which is extremely vague, informal, and slogan-like). Although it might be reasonable to meet somewhere in the middle of this continuum, science education researchers have yet to establish a priority with a more formal and rigorous mode of expressing, analyzing, and representing key nature of science ideas and terms to one another or to students (i.e., the context of justification). These issues and related concluding remarks are briefly elaborated upon in the discussion section next. The aim of the discussion that follows is to bring the key ideas developed in this article full circle back to concerns of education and educational research, and in particular nature of science research.

**Discussion**

This article examined the very critical and key generalization or contention that our conception of nature of science, like our conception of scientific knowledge, is tentative and dynamic. This assertion seems reasonable and to be a generalization as claimed when we consider that the different aspects of nature of science (such as the creative, human, and empirical aspects) are subject to change to some degree and in
specific contexts. For example, future studies may provide evidence to suggest that scientific knowledge is more or less creative, empirical, and theory-driven than presently thought (although these are certainly difficult things to measure precisely). The possibility of these small scale or local types of changes are accepted and even expected by most nature of science scholars and researchers and are not being questioned here. However, if followed through to its logical consequences (as all generalizations should be in science and other areas) and without limits and clarification, a tentative conception of the nature of science does not exclude the possibility of completely rejecting each aspect (or tenet or idea or concept) of the nature of science, regardless of how slim that possibility might be. It is extremely difficult to imagine science as non-empirical, non-human, and theory-less. However, it is even more difficult to imagine that the tentative nature of science is tentative (without important qualifications), as this position clearly suggests that scientific knowledge could be viewed as absolute and certain (or something less than tentative). Could anything fitting this profile continue to be called science as we know it today? These are some of the potential wrong turns and misconceptions afforded to anyone who considers the view that our conception of the nature of science is tentative. These facts strongly suggest that this claim is not a well worked out, well constructed, and thoroughly examined generalization as asserted, but rather is a slogan and an example of sloganeering, or at least well along the road to that end of this contrasting continuum. Matthews (1997, 2005) and others (e.g., Allchin, 2004; Carifio, 2005; Fensham, 2004) have written fairly extensively about this problem in science education and elsewhere and the many and important consequences of slogans and sloganeering as opposed to well constructed and thoroughly examined generalizations which will be addressed in more detail below. The point focused on here, however, is the many and convoluted logical inconsistencies of this assertion and claimed generalization about the nature of science and its potential for generating and contributing to misconceptions.

These logical inconsistencies, if noticed at all, are perhaps less of a problem for the sophisticated scholar, educator, or reader who may be more capable of dealing with and overcoming conceptual ambiguity or recognizing and dealing with slogans as opposed to well constructed and thoroughly examined generalizations. The concern here, therefore, is with the unsophisticated reader who knows enough to try to follow a chain of thought, but does not have the sophisticated knowledge structures to overcome these logical problems. Since we know that students and many teachers have difficulty with epistemic terms and concepts, great care should be exercised in constructing and using such terms and concepts – especially when they are used or proffered as generalizations (as opposed to slogans).

In their advocacy of teaching the nature of science, science education researchers have attempted for the most part to avoid intractable philosophical debates. This is why Osborne, et al. (2003) accept a “vulgarized” (simplified) view of the nature of science and why
Lederman, et al. (2002) state that “many disagreements about the specific definition or meaning of NOS that continue to exist among philosophers, historians, sociologists, and science educators [such as the existence of an objective versus a phenomenological reality] are irrelevant to K-12 instruction” (p. 499). But just how vulgarized (even using a subjective and ordinal metric) can our perspectives become and what are the consequences of such perspectives in the classroom? That said, it is interesting and somewhat surprising that Lederman and colleagues would address a point and generalization that, as has been shown here, is philosophically and epistemically complex and presumably, in their opinion, irrelevant to K-12 instruction.

It should also be noted at this point that philosophically complex ideas have an insidious way of worming their way into our thoughts and actions despite our best attempts to keep them “neutralized” (Bartlett, 1932; Ryle, 1949). This “worming effect” of philosophically complex ideas is especially important to consider when developing instructional materials related to the nature of science where it can be assumed that K-12 students (and even college and pre-service students) are more susceptible to such effects and associated misconceptions (both unconsciously and consciously formed) due to their lack of philosophical training and experience.

The title of this article asked if our conception of the nature of science can be tentative. The answer is that our general conception of the nature of science can be viewed as tentative as it relates to the many different nature of science aspects (or tenets) in most instances, acknowledging the fact that the logic of this statement is flawed to some degree (which would seem to be a very helpful instructional point). However, this generalization is extremely problematic when applied to the core aspect (or tenet) of nature of science studies – the tentativeness of scientific knowledge. But K-12 students and teachers do not need to consider or reconcile “the tentativeness of tentativeness problem” in order to develop a sound appreciation and understanding of the nature of science.

So how can the logical problems associated with the tentative conception of the nature of science be balanced against the advantages to studying the nature of science (without just ignoring the criticisms in this article)? We have four recommendations to address this issue: First, if science educators prefer to adopt a simplified view of the nature of science, as many now do, then overreaching generalizations like the one analyzed here should not be made lightly or in passing. Indeed, in discussing Wittgenstein’s view of philosophy, Richter (2006) makes the following statement about generalizations that applies equally well to education as it does to philosophy:

When nonsense is spoken or written, or when something just seems fishy, we can sniff it out. The road out of confusion can be a long and difficult one, hence the need for constant attention to detail and particular examples rather than generalizations, which tend to be vague and potentially misleading. [italics added] (p. 6)
This quote suggests, as does this article, that science educators and educators in general need to be careful when making generalizations about the nature of science and to anticipate ways in which what we say and teach can be misunderstood by learners.

Second, science educators should not operate and teach under the assumption that our conception of the nature of science is tentative but rather operate and teach under the assumption that our conception of the nature of science is non-controversial (a term used by Lederman, et al. (2002) to describe the five tenets of NOS in Figure 1). For example, it is less problematic to accept and teach the idea that “tentativeness in science is non-controversial” versus the idea that “tentativeness in science is tentative.” That said, a more fine-grained analysis of tentativeness and change is needed in nature of science studies and research. Indeed, until the word “tentativeness” includes qualifiers relative to degrees (i.e., how tentative and what is the probability of change, as suggested briefly in Figure 1) it is almost a totally meaningless and empty word, concept, and statement as the ambiguity and range of possible meanings is too great and too different for students (and even researchers) to effectively conceptualize.

Third, science educators and particularly nature of science researchers should consider and recognize that science and philosophy have very different forms and standards of discourse (Thagard & Beam, 2004) and be aware of possible logico-linguistic inconsistencies and misconceptions related to nature of science studies and instruction.

Fourth, nature of science researchers need to understand that our general views and conceptions of the nature of science need, at the very minimum, to be logically consistent with the individual tenets that define and operationalize the general conception(s) to whatever extent this logical consistency is possible. Indeed, this type of logical consistency between the general and the specific features of a construct is actually a form of internal validity that also influences important issues relative to construct validity and generalizability (Kerlinger & Lee, 2000). In cases where inconsistencies between a general proposition and its defining elements are identified, qualifications and exceptions need to be clearly articulated and discussed. Of course, none of these recommendations is easy to realize, especially in the classroom, but awareness of these issues is likely to be helpful in nature of science instruction, research, and assessment.

Finally, this article attempts to dissect, analyze, and reflect on a critical and key assertion made by science educators related to a central feature of nature of science studies (i.e., tentativeness). Ironically, this specific exegesis and analysis is the same type of qualitative and exploratory strategy recently advocated by leading science education researchers to better understand students' views and statements of the nature of science. In fact, one of the virtues of the View of Nature of Science (VNOS) questionnaire developed by Lederman, et al. (2002) is its ability to perform more in depth and contextualized studies of specific comments, propositions, and assertions made by students relative to the nature of science – a purported limitation of the strictly quantitative
assessment models. Because of the inherent complexity and subtlety of language, especially philosophical and epistemic discourse, nature of science researchers stand to gain from routinely applying the critical linguistic-conceptual analysis of statements made by students to their own statements and views. As Wittgenstein notes—and as many nature of science and science education researchers have indirectly documented and experienced: “Language sets everyone the same traps; it is an immense network of easily accessible wrong turnings” (as cited in Richter, 2006, p. 7). Perhaps by paying closer attention to the language we use in nature of science studies and research we can do a more effective job teaching students about the nature of science by anticipating misconceptions (or “wrong turnings”) and developing more coherent, differentiated, and satisfactory instructional models of the nature of science.

In a word, we need to employ well-formulated, well constructed, and thoroughly examined generalizations, assertions, concepts, and claims about the nature of science and its various components as opposed to vague, ill-defined, and logically problematic ones that upon examination quite clearly turn out to be no more than slogans, quasi-slogans, or statements very close to these kinds of statements with all of their many associated and undesirable consequences and problems for both nature of science and science education in general. More work clearly needs to be done in developing more contextualized and coherent theoretical views and models of change as a whole in science education versus “fact points” or “fact islands,” which is essentially a behaviorist view of scientific knowledge and knowledge in general and consequently the learning and understanding of both. Research along these lines is currently underway.

REFERENCES


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BIOGRAPHICAL STATEMENTS

PLEASE PROVIDE brief biographical statements for EACH author - just 3-4 lines outlining what and where EACH has studied, taught, and written and current research interests.